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*Optimal Allocation of Land for Training and Non-Training Uses (OPAL)*

# Using Simple Environmental Variables to Estimate Biomass Disturbance

Natalie Myers, Daniel Koch, Andrew Fulton, Anne Dain-Owens, Dick Gebhart, Ryan Busby, James Westervelt, and Heidi Howard

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# Using Simple Environmental Variables to Estimate Biomass Disturbance

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# Abstract

Proper management of military training lands is critical to ensure availability of training lands, and thereby ensure mission readiness. However, installation land management often supports a broader mission than simply maintaining the land in a condition suitable for training, including activities as agriculture and grazing outleases, and protection of habitat to conserve Federally listed threatened and endangered species. Proactive land management practices that support such potentially conflicting land uses must take a systematic approach that considers, coordinates, and integrates complex land impacts. Development of the Optimal Allocation of Land for Training and Non-Training Uses (OPAL) Program was undertaken to meet this need. This phase of work developed algorithms for estimating cumulative land disturbance on military training lands through above- and below-ground biomass responses. Algorithms developed here specifically focused on four aspects of the relation between above- and below-ground biomass and natural resource disturbance: (1) use of above- and below-ground biomass to quantify disturbance, (2) forecasting soil temperature and moisture as a consequence of weather, (3) distribution of training and its impacts on biomass, and (4) impacts of burning/haying on land management.

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# Preface

This study was conducted for the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASAALT), under A896 Project (AMSCO 622720089600), "Optimal Allocation of Land for Training and Non-Training Uses." The technical reviewer was Alan B. Anderson, CEERD-CV-T.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, William Meyer was Chief, CEERD-CN-N; Michelle Hanson was Chief, CEERD-CN; and Alan Anderson was Technical Director, CEERD-CV-T. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

The Commander and Executive Director of ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

# 1 Introduction

## 1.1 Background

Proper management of military training lands is critical to ensure availability of training lands, and thereby ensure mission readiness. Sustainable training land management complements the military mission by minimizing detrimental environmental impacts of maneuver training. Army Regulation (AR) 350-19 assigns responsibilities and prescribes policies for maximizing the capability, availability, and accessibility of ranges through the Sustainable Range Program (SRP). A core component of the SRP is the Integrated Training Area Management (ITAM) Program, which provides the Army the capability to manage and maintain training lands by integrating mission requirements with environmental requirements and appropriate land management practices (HQDA 2005). To date, many studies have estimated the impacts of military training activities on installation lands (Ricci et al. 2012).

However, installation land management practices often support a broader mission than simply maintaining the land in a condition suitable for training. The Army's "ecosystem approach" to land management supports multiple-use activities, when those activities are compatible with mission requirements, including agriculture and grazing outleases (USAEC 2011). As a Federal agency, the Army is also required by the US Endangered Species Act (ESA) to conserve Federally listed threatened and endangered species (TES) on installation lands. The Army often makes proactive management efforts to eliminate potential conflicts between threatened, endangered, proposed, and candidate (TEPC) species and military mission and management efforts (USAEC 2009). Installations' Integrated Natural Resources Management Plans (INRMPs) include practices that benefit the conservation of species of concern, e.g., by incorporating plans to enhance or preserve critical habitat through such management practices as controlled burns.

In general, military training land management and maintenance practices support two primary objectives: (1) to maintain lands for military training and (2) to meet environmental requirements. Proactive land management practices that support potentially conflicting land uses must take a sys-

tematic approach that considers, coordinates, and integrates complex land impacts. Development of the Optimal Allocation of Land for Training and Non-Training Uses (OPAL) Program was undertaken to meet this need.

## 1.1 Objective

The overall technical objective of the OPAL project is to develop approaches to estimate cumulative land disturbance on military training lands through above- and below-ground biomass responses by merging current biomass disturbance methods/models with OPAL field data to capture disturbance regimes for military land managers. The specific objective of this phase of work was to define algorithms to establish the relationship between land use and biomass.

## 1.2 Approach

The objectives of this stage of OPAL research were met through the following steps:

1. A literature review was conducted to identify and examine current methods, models, and tools used to estimate above- and below-ground biomass responses to disturbance.
2. Information derived from the literature review, combined with OPAL field data, was used to develop algorithms that define the relationship between land use and biomass.
3. Algorithms developed here specifically focused on four aspects of the relation between above- and below-ground biomass and natural resource disturbance:
   a. use of above- and below-ground biomass to quantify disturbance
   b. forecasting soil temperature and moisture as a consequence of weather
   c. distribution of training and its impacts on biomass
   d. impacts of burning/haying on land management.

## 1.3 Scope

This effort addresses the interplay among weather, military maneuver training, and land management, including haying and burning. Equations developed in this work capture the combined interaction of these land aspects on the health of the vegetation that provides training realism and protection against erosion. With appropriate calibration, the equations are intended to be useful for vegetation types across the United States.

## 1.4   Mode of technology transfer

It is anticipated that the results of this work will be used to develop spatial and statistical models that will incorporate the effects of military disturbance and land management activities into a software-based landscape simulation model system.

# 2 Optimal Allocation of Landuse (OPAL)

The US Department of Defense (DoD) is unique in the type, frequency, and magnitude of its land uses. Although the effects of most land uses on installations (e.g., vehicular maneuvers, dismounted training, control burns, grazing, forestry, wildlife management, etc.) are somewhat understood, the cumulative and interactive effects of these activities have only been explored superficially. The Optimal Allocation of Land for Training and Non-Training Uses (OPAL) work package was undertaken to research the effects of combined military training and land management activities on the health of maneuver area grasslands by filling significant knowledge gaps in cumulative and ecological responses, and by providing predictive land management capabilities.

Anecdotal field observations have noted complex interactions between military and land management activities. OPAL's underlying hypothesis, based on these observations, is that land use activities can be synergistic, anergistic, or neutral — depending on the characteristics of the interacting disturbance regimes. If this hypothesis is true, then the results of OPAL research may enable the Army to avoid the detrimental effects of multiple land use activities, and by careful management, to actually improve long-term training capacity.

The overall goal of OPAL research is to provide military land managers and the training community at multiple levels with a common view of training land use and of the interconnectivity between each land use and its impacts on training land quality. This stage of research included field experiments to quantify the effects of trafficking, burning, and haying/cutting on maneuver areas. The mathematics presented here combine the OPAL field study results with current methods, models, and tools used to estimate above- and below-ground biomass[*] responses to disturbance, and to assess the applicability of these results to military land management. These equations provide the foundation for development of a simulation model of vegetation response to training and land management.

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[*] For the purposes of this research, "biomass" is defined as above-ground (shoot) and below-ground (root) organic matter.

This stage of research developed algorithms for projection scenarios that provide predictive capabilities for land impacts from current and future weapon systems. Data derived from this research may also feed into existing models such as the North Atlantic Treaty Organization (NATO) Referenced Mobility Model (NRMM), which allows for improved modeling capabilities. To this end, OPAL research may be categorized into four interrelated and linked avenues of investigation (Figure 1):

1. Land metrics
2. Synergistic and anergistic interactions
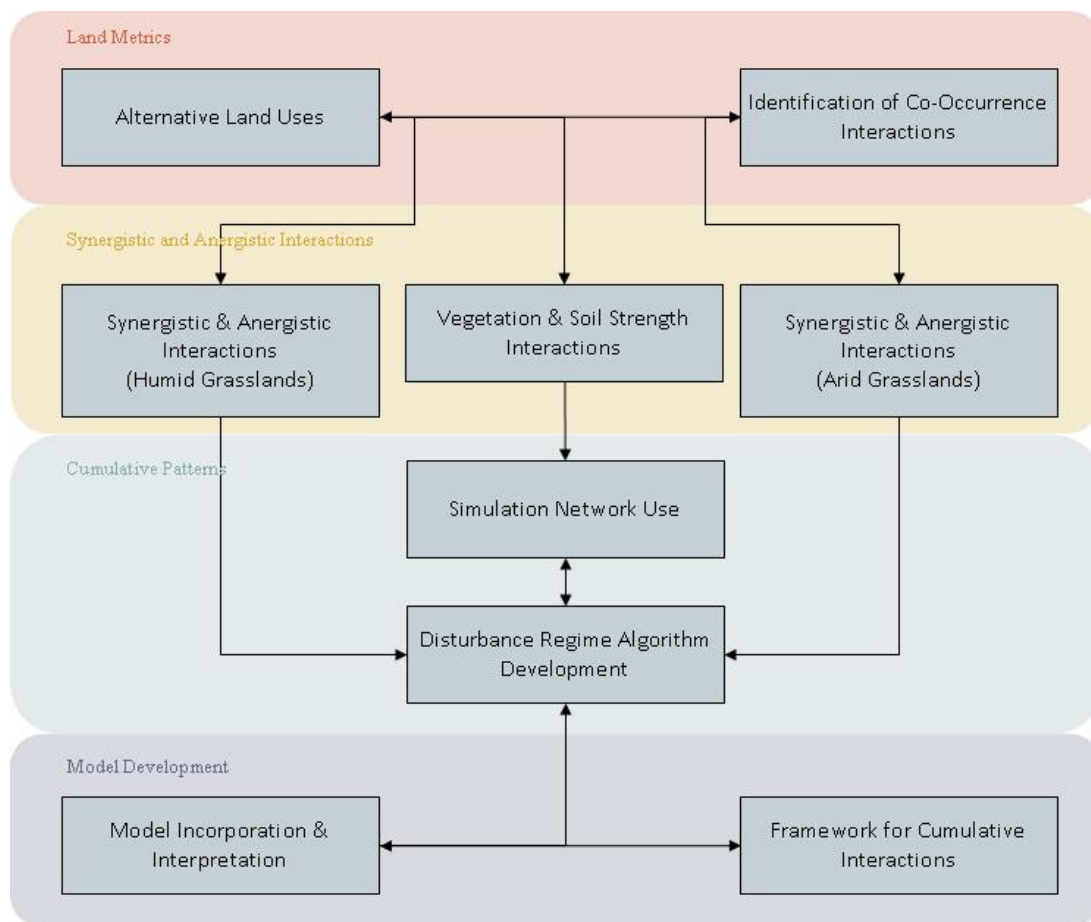3. Cumulative patterns
4. Model development.



Figure 1.  OPAL work package: Project titles and work flows.

## 2.1 Land metrics

"Land metrics" research defines impact types and regimes using a hierarchal matrix and prioritization scheme. It provides key scientific knowledge needed to identify impacts on military training lands. Specifically, this research will: (1) identify military- and nonmilitary-specific land use activities and categories, (2) evaluate the feasibility of co-occurrence for land use activities, and (3) prioritize research needs based on co-occurrence activities. Smith (2011) and Price et al. have documented the results of these efforts.

## 2.2 Synergistic and anergistic interactions

"Synergistic and anergistic interactions" research was included three projects that conducted controlled replicated field studies to test combinations of land use interactions. Each focused on the influences of training and land management practices on: (1) above- and below-ground biomass; (2) overland flow; (3) survivability of vegetation from repeated impact; and (4) selection of Best Management Practices. Howard et al. (2013) and Fulton et al. (2013) document the field data and statistical analyses.



Figure 2. Field data collection.

## 2.3 Cumulative patterns

"Cumulative patterns" research developed methodologies and tools to investigate and quantify military disturbance regimes. This research included two projects:

1. *Simulation Network Use*, which extracted military maneuver data to determine cumulative land use interaction information from the existing

suites of military training, testing, and simulation systems to optimize land use allocation. This effort identified and examined simulation software systems currently being used for military training/maneuvers, and initiated the development of extraction tools that collect relevant land use information at a level of resolution that is beneficial to land managers.

2. *Disturbance Regime Algorithm Development*, which merged current algorithms and models used to estimate disturbance levels with OPAL field data to capture disturbance regimes for military land managers. Svendsen, Koch, and Howard (2013) and Myers et al. (2011) have documented the results of these efforts.

## 2.4   Model development

"Model development" research incorporated the results of the previous three research components to develop a conceptual approach for defining optimal installation land allocation problems. The objective of this research was to capture the optimal allocation capabilities in end-user software. Koch et al. (2013 a&b) documented this effort.

# 3   Literature Review

## 3.1   Ecological succession

"Ecological succession" refers to the (more or less) predictable and orderly changes in the composition or structure of an ecological community. Ecological succession is commonly initiated by some form of disturbance (e.g., fire, erosion, harvesting) of an existing community (Figure 3). The concept of ecological succession goes back to the 14th century. The French naturalist Adolphe Dureau de la Malle was the first to make use of the word "succession" in reference to the vegetation development after forest clear-felling (May 1973, Allen and Starr 1982).

In 1917, J. T. Jardine developed the first scientific survey method characterizing succession. Jardine's method involved a careful visual examination of the land to provide a written record the resources. He recorded the following data on rangelands  (Jardin and Anderson 1919):

1.  A topographic map showing watering places, roads, fences, and cabins
2.  A classification of the rangeland into 1 to 10 grazing or vegetation types
3.  The percentage of the rangeland covered by each forage species
4.  A descriptive report of each grazing or vegetation type, including the suitability of each type for each kind of grazing animal
5.  A map of the timber
6.  Samples of the major species present on the rangeland.



Figure 3.  Succession after disturbance: A boreal forest, (left) 1 year, and (right) 2 years after a wildfire.

Jardine's survey method was highly credible in its time, but because it was based on visual estimates of the ground cover of each species rather than on direct measurements of the volume or weight of the forage produced by each plant species, it did not give an accurate measurement of productivity or yield. Survey results were highly dependent on the investigator.

In 1933, A. R. Standing introduced the concept of using measured volumes of vegetation rather than visual estimates of cover (Standing 1933). At this time, other modifications were made to the Jardine method, and these were finally standardized and adopted by the Soil Conservation Service (SCS), the Bureau of Land Management (BLM), and the US Forest Service (USFS). Although more quantitative than the original reconnaissance method, the surveys still depended on a number of subjective criteria for estimating forage production or carrying capacity and neglected any data on soil conditions, wind and water erosion, or other factors that would allow a more comprehensive evaluation of ecological communities. More important, the method was not linked to any theoretical base that suggested how the forage composition data that were collected could be interpreted as indicators of ecological conditions on communities. Forage production, rather than the state of ecosystems was evaluated (NCR 1994).

Fredric Clements solidified the theory of community dynamics—how plant communities develop and change. To Clements, succession sequences of communities were highly predictable and culminated in a climatically determined stable climax. This climax theory rested on the assumption that vegetation could be classified into formations that represented a group of plant species that acted together as if they were a single organism. Communities would be classified on the basis of differences in climax plant community composition and would be assessed on the basis of the divergence of the current plant composition from the climax plant community composition (Clements 1916).

E. J. Dyksterhuis, a student of Clements, was pivotal in moving from the old method of determining functional capacity, which used visual estimates of forage composition, to a new method based on observations of the succession of conspicuous vegetations, i.e., the replacement of one set or type of plants by another. Dyksterhuis refined the climatic climax community by proposing that different climaxes coexist as a function of soil or topographic or geographic differences within a similar climate. He also as-

serted that human disturbances often drove the plant composition toward the early stages of succession, whereas natural successional processes drove plant composition toward a climax community. Therefore, by adjusting the grazing pressure or the duration or season of use, rangeland managers could maintain rangelands at any stage of succession. Dyksterhuis proposed a quantitative system for assessing whether a community was at an early or late stage of succession by analyzing the behaviors of three classes of plant species: decreasers, increasers, and invaders (Dyksterhuis 1949).

Dyksterhuis' use of successional stages as the measure of the condition of rangelands had great appeal. By 1950, the standard concept in US land management became the measurement of range condition as the degree of departure from climax plant community vegetation of a defined range site and the succession-retrogression model of rangeland development. To varying degrees, the SCS, BLM, and USFS all adopted the concept.

Today the SCS, BLM, and USFS continue to evaluate successional change on lands by comparing the composition and annual biomass produced by the existing vegetation with a previously determined benchmark plant composition and production. The SCS defines this benchmark as the climax plant community for that range site, and the USFS and BLM, respectively, define it as the potential natural community for that ecological type or ecological site.

The relationship between successional stages and the integrity of its ecological processes —that is, its health— is uncertain. Lauenroth (1985) noted that species that are not part of the climax vegetation can also conserve the soil, water, and productiveness of rangelands. The effectiveness of vegetation in protecting soil is more a function of effective soil cover than plant composition, since effective soil cover is more closely tied to the type and pattern of cover than it is to plant composition. Loss of minor species may not be indicated by a change in range condition or ecological status rating if these species make up a small percentage of the plant composition and annual biomass production. The loss of minor species, however, may indicate change in nutrient cycles caused by reduced diversity in rooting depth or changes in energy flow because of reduced period during which the remaining plants photosynthesize.

P. T. Tueller described a process of site degradation that began with the loss of plant vigor and seed production and that led to the death of individual plants and a reduction in litter cover and plant density (Tueller 1973). These changes caused changes in plant cover, distribution, and potential for reproduction. Total biomass production or the annual production of individual species was reduced. Further deterioration led to reduced litter accumulation, the formation of soil crusts that retarded germination, and altered plant growth forms. Reduction in soil cover and litter led to soil erosion and the disruption of nutrient cycles. Eventually, the site potential was seriously impaired (Tueller 1973).

## 3.2 The Army perspective

### 3.2.1 Training lands as "service provider"

In a broad sense, well maintained installation lands provide multiple "services" in terms of the activities that they support, whether those activities are military training, agriculture and grazing outleases, or preservation of habitat for TES. Degradation of installation lands reduces the diversity of the services that those training lands can provide, and severe degradation can be irreversible. Overtraining, drought, erosion, and other human and naturally induced stresses have caused severe degradation in the past. The capacity of training lands to sustainably satisfy the need for the valuable services depends they provide depends on the interaction of climate, plants, and animals in particular geological and topographic setting. Over time, these interactions develop the soil and thereby produce particular kinds and amounts of vegetation that enable the lands to adjust to changes in their environment (or in their management). These interactions also give lands the ability to resist the destructive effects of such extreme events as droughts and intense rainstorms (Ritsema et al. 2005).

### 3.2.2 Maintenance of training lands

The Army is responsible for administering more than 15 million acres of Federally owned land in the United States (HQDA 2006). Since the passage of the National Environmental Policy Act of 1969 (NEPA) and the publication of AR 200-2, *Environmental Effects of Army Actions* (1980), the military has been required to minimize or avoid both short and long-term environmental impacts caused by military training. Since there is a limited amount of available land for military training, it is in the Army's

best interest to protect these areas to fulfill their mission requirements for realistic training and testing. To meet this need, the military initiated the ITAM program with the goal of long-term management of training lands. A similar program, initiated specifically for ranges, was ultimately merged into the Army's SRP with the overall goal to achieve optimum sustainable use of military lands and ranges.

Management of military lands focuses on continued use of those lands for training and testing. It is US Army policy to maintain training lands in a condition that closely mimics the natural conditions under which actual warfare would be conducted (i.e., to maintain training realism). Including training, many human activities take place on Army training lands, such as forestry operations, agricultural outleasing, recreational activities, etc. These uses inevitably lead to natural resource disturbance. The use of military vehicles during training, for example, results in soil disturbance and vegetation loss, which consequently increases soil erosion rates, sedimentation in streams, habitat degradation, and numerous other secondary and tertiary effects. Forestry activities such as timber harvest and prescribed burns can result in similar soil disturbance and/or loss of vegetation and subsequent impacts to varying degrees. Army land managers must consider how these activities, occurring in conjunction and over time, cumulatively affect both the environment and quality of training lands.

### 3.2.3  Cumulative impacts

Cumulative impacts are defined as effects that result from the incremental actions when combined with other past, present, and foreseeable future actions, i.e., training duration, land management practices, changes in training doctrine, etc. (40 CFR 1508.7 and 1508.8). NEPA and the Environmental Analysis of Army Actions; Final Rule (32 CFR Part 651) require Federal agencies to evaluate the environmental implications of their plans, policies, programs, and projects, at the same time that traditional economic and technical evaluations are underway. The NEPA process requires consideration of direct, indirect, and cumulative impacts. An Army Environmental Policy Institute (AEPI) study also defined the critical need to account for cumulative impacts in the installation master planning process (Keysar 2002). Likewise, SRP goals are to understand and manage long-term impacts to ensure the sustainability of military mission.

The process of site degradation/succession is driven by a complex of interacting factors; no single factor predominates. The problem with current conservation practices that measure plant composition and biomass is not that those attributes are unimportant; rather, the problem is that they are typically the only attributes measured. On the other hand, measuring a great many complex, interacting factors takes a great deal of time and study, and the results of that data collection and study are not easily transferable from site to site. Consequently, range managers have typically relied on their accumulated observations and instincts through the years.

### 3.2.4 Carrying capacity

"Carrying capacity" is one of the important land management concepts embedded in the ITAM program. The concept of carrying capacity is derived from ecosystem science principles, refers to the amount of cumulative land use, or "load" (usually referring to a particular type of use, such as livestock grazing, recreation, or military training), that a given parcel of land can sustainably accommodate. Carrying capacity is a complex, integrated variable that is a function of the inherent site characteristics (e.g., soil, slope, aspect, and climate) and biological regime (e.g., flora, fauna, vegetation community, structure, and composition) of the natural environment. It can be quantified by scientific observation, experimentation, and measurement and estimated using professional judgment. Load, or land use (e.g., military training), can be quantified by type, intensity, and frequency, based on established military doctrine. For the Army, land carrying capacity is defined as the amount of training and testing that a given parcel of land can accommodate over time in a sustainable manner (HQDA 2006).

Maintaining land use at or below the carrying capacity allows the landscape to recover naturally over time. When the amount of use (load) placed on the natural system exceeds the carrying capacity, a critical threshold is reached that can result in accelerated degradation or ecosystem change. Human intervention, in the form of land maintenance and rehabilitation, is essential to prevent these thresholds from being crossed. These practices may include reseeding of damaged areas, planting of trees and shrubs, making structural improvements to streams, and implementing other common land rehabilitation and maintenance solutions. The goal of the ITAM program is to sustain the long-term capacity on Army

training and testing lands through a balance of usage, land condition trend monitoring, and land maintenance/repair.

In 1995, ERDC-CERL initiated the "Land Based Carrying Capacity" research and development package. The objective of this work package was to address the requirement of sustainable training and testing land carrying capacity. A key component of this capability was the Ecological Dynamics Simulation (EDYS) model. The model provides the capability to predict responses of training lands to both military and non-military stressors and facilitates linking the cost of training and testing land maintenance to the actual level of training (McLendon et al. 1998).

### 3.2.5 Predictive capability

EDYS was initially focused on addressing issues of scale. Different ecological processes operate at different spatial and temporal scales (Levin 1992). The traditional Army approach was to have an experienced land manager make a judgment regarding the status and trend of the resources in question. Models were viewed as either:

1. Overly general and of little practical value in evaluation of specific management scenarios
2. Overly specific and therefore, limited to only one or a few sites
3. Very complex, requiring extensive calibration with site-specific data that are not available
4. Not sufficiently focused, e.g., the endpoints they evaluate, such as soil erosion, are important, but the endpoint is only one of several important aspects of ecological dynamics (McLedon et al. 2001, Childress et al. 2002, Childress and McLendon 1999, Childress 1999).

In addition to EDYS, a number of methodologies have been developed and are used to estimate military training land carrying capacity (CAA 1996, Anderson et al. 1999, Shaw and Diersing 1989, Warren and Bagley 1992, Wilson 1988, Childress and McLendon 1999). Case study examples may be found in Hochstrasser, Peters, and Fehmi (2005); Guretzky Fehmi, and Anderson (2006); and Byrd (2005).

Common to each of the methods is a submodel that accounts for the effects of land use activities. These models reflect considerable research that successfully quantifyies the impacts of land use activities on natural resources (Shaw and Diersing 1990, Milchunas et al. 1999, Prosser et al. 2000, Herl

et al. 2005). Unfortunately, little data were and are available to populate
these models to accurately characterize the spatial and temporal impact
regimes of military activities in terms of the intensity, frequency, duration,
and spatial extent of impacts. Moreover, these models incorrectly assume
that interactions between military and non-military activities are already
understood (Anderson et al. 2005). Together, these deficiencies made it
difficult for these existing models to successfully estimate military training
land carrying capacity.

During the late 1990s into the 2000s, Army research focused on isolating
the impacts of single activities on the landscape, particularly the impacts
of military vehicles on vegetation. Examining vehicle impacts in natural
environments began in the 1980s largely in response to controversies gen-
erated by increased recreational use of off-road vehicles on Federal lands.
Nevertheless, this research was typically observational in nature and the
specific activates creating the impacts were not quantified in terms of du-
ration, frequency, extent, and vehicle type. Thus this early research only
indirectly linked natural resources impacts with levels of training load.
Post ITAM (1995), studies better quantified military vehicle impacts
through the use of classical experimental designs, more powerful observa-
tional techniques (like satellite imagery), and a variety of statistical design
methods. ERDC-CERL SR-01-17 (Fehmi et al. 2001) summarized the ref-
erences contributing to this body of work.

Since the end of EDYS's project, the understanding of the impacts of off-
road and military vehicle activities has dramatically increased. However,
the effective use of this information in land management decision making
has been limited.

In 2011, range managers at Canadian Forces Base Suffield initiated the
"Range Condition Assessment" study to quantify the impacts of cumula-
tive land activities on range conditions. Range managers devised a meth-
odology by which they divided the post into a 30-m vector grid and annu-
ally charted the land management activities occurring within each vector
alongside the landcover quality. The study used simple regression analyses
to find correlations between specific management patterns and resulting
land quality characterization (Smith and Gartry 2011). With less than 1
year of data collected, the results are as yet inconclusive. Still by design,
the study will only provide a long-term trend analysis, not the short-term

predictions/land management optimization timescale that ITAM land managers require, and that EDYS research strived to achieve.

## 3.3   Recent advances

The current state for both indirect and cumulative impact assessment is evolving. However, recent assessments tend to be characterized by limited analysis and supporting knowledge of military specific impact interactions. A published review of Environmental Impact Statements (Keysar 2002) found that cumulative impacts analyses have received insufficient time or resources to adequately consider these impacts. While methods have been developed to account for cumulative effects in NEPA documentation processes, this approach is useful for quantifying the only additive cumulative effects of multiple land uses on a common resource (i.e., total loss of forest land due to different land use activities), it does not account for the interaction among land uses with respect to military actions.

Current ecological research has questioned whether the concept of well-defined, predictable, and reversible changes along a successional gradient holds for all or the majority of ecological communities. Ecologists have developed theories that allow for multiple equilibriums and for transitions between alternative vegetational states that are not easily reversible. Investigators have attempted to describe the mechanisms that produce such complex dynamics on communities. In some cases, the random occurrence of fire, drought, or changes in human activities have produced changes in communities that do not appear to follow a readily discernible successional sequence. Today, complementary sciences are being coordinated to better explain the dynamics of vegetation, such as:

* application of concepts of population dynamics that are derived from the field of animal ecology
* tracking of nutrient cycling and energy flow as system alternatives to quantification of biomass
* use of geospatial science and remote sensing tools to create digital imagery to characterize landscape structures
* use of computer science's ability to manage complex problems using system dynamic and agent-based models that allows analyses of the operational characteristics and physical states of ecological communities.

## 3.4   Unresolved problems

Despite these academic advances, no coherent theory has yet been suffi-
ciently tested to replace current successional concepts (Bastian et al. 2006).
In fact, only a small minority of military ranges, or even parks, forests, and
nature reserves have and use succession modeling tools in management.
Many factors contribute to this situation (Kessell 1981). First, succession
models are simply not available for most of these areas. Most succession
modeling efforts have been conducted in a few small areas for which a good
database was either already available or constructed during the study. Ap-
plications to new areas is certainly possible using existing and tested mod-
els, but this cannot be accomplished without the collection of new data for
local calibrations, fine tuning, and validation. The kinds and amounts of
new data required depend on several factors, including the type of succes-
sion model employed; previous data collection and research on community
composition; species characteristics and succession; and the availability of
data from other ecologically similar areas. The greater the difference be-
tween communities originally modeled and those in the new area, the larger
is the effort required to obtain the needed information.

The second problem, related to the first, is the inadequate understanding
of the characteristics, adaptation, and interactions of species populations.
Much progress has been made in this area in the last decades; much more
remains to be done. Too many models must estimate, extrapolate, or
simply guess these parameters. This not only detracts from the models'
capabilities, but also increases the difficulty in applying them to new areas.

Another related problem is modeling the compound effects of disturbance
intensity, periodicity, and frequency. Some recently developed models
(i.e., Forest Planning Language and Simulator [FORPLAN]) do include in-
tensity and/or periodicity as independent variables that affect the post-
disturbance community development; at least one model allows an inter-
action of intensities and periodicities of fires (Kessel and Potter 1980).
However, since these models depend on historical successions for part of
their database, their reliability under disturbance regimes without histori-
cal precedence is generally unknown. Repeated disturbances at high fre-
quencies pose a still greater problem. Military range managers, for exam-
ple, ask a question for which there is no reliable answer: "But what will

happen in the long-term if we prescribe burn this community every five years for the next century?"

An even greater problem is posed by the need to model not only very different kinds of disturbances, but also the interactions among them. Models of fire, insect, and grazing disturbances are common, but very few models can address all three disturbances or their interactions. Problems such as these highlight limitations not only in the models themselves, but also in the databases on which they depend. Such complex problems challenge researchers to improve the basic models, and both researchers and managers to initiate progressive programs of resource data collection. Even if researchers could produce the perfect model of biomass changes after disturbance, and guarantee it to be without error, several problems would still remain.

Land management agencies manage not only to maintain the vegetation itself, but also animal populations, watershed quality, recreational opportunities, and resource production. Perhaps these other considerations can be derived at least in part from knowledge of vegetation dynamics, but the burden is on the researcher to provide this interpretation. Disturbances and disturbance management affect many other ecosystem components, including dead material, nutrient pathways and stores, special habitats such as logs and snags, and aquatic communities. Most succession models address these considerations inadequately or not at all.

An equally important limitation of most succession models is their inability to address an entire landscape mosaic. A manager who may wish to optimize species diversity or wildlife habitat, must consider it on the level of the entire park, forest, or reserve—not simply on the level of a single community. For example, to determine the best fire management plan for an individual drainage area, the manager may need to consider:

- whether adequate suitable habitat is available for large mammals that will be temporarily displaced by the fire
- what kind of fire would produce a mosaic of intensities and thus leave undisturbed "island" refuges for small mammals
- whether seed sources are available for the obligate seeding tree and shrub species
- what affect this fire and the successional responses of the communities will have on the diversity of the entire drainage.

Additional considerations include the size, shape, placement, and timing of disturbances; the uniformity or patchiness of the environment; and the interaction of controlled disturbances and potential future (unknown and potentially uncontrollable) disturbances. These are extremely important considerations that succession models have only recently begun to address.

The metrics used within natural resources models (or the language used to express them) can vary, but in general, it is possible to convert or adjust them for comparison of like units/measurements, i.e., animal units for grazing verse elk populations. This cannot be said for measurements/parameters currently employed to access military training impacts, i.e., Maneuver Impact Miles (MIM) or the standardized collection of scientific data on ecological conditions (the ITAM program's Range and Training Land Assessment protocol). A standardized method of metrics has not been developed that assesses military training quality or military impacts, much less military impacts over time and space in conjunction with other natural resources management practices. Currently used models and methods for land management may be appropriate, but cannot provide concurrent, meaningful representation of the ecosystem health and capability to sustain military training due to the lack of common metrics. The accurate assessment of impacts is often limited by the variability and vagaries of technical data available to support these assessments. While military impact studies have historically been used to assess the impact of military stressors on installation natural resources, these studies have provided limited information. For example, data collected on a single training event at a single scale may not be sufficient to assess the complete range of impacts associated with training and testing activities.

The last unresolved problem to be discussed here is the need to provide modeling tools to managers in a readily usable form. One good approach is to develop integrated resource management modeling systems and databases. Such computer-based systems place numerous tools and considerable resource information at the managers' fingertips, but shift additional responsibility on the researcher to provide results and techniques in a user-friendly format.

# 4 Disturbance Regime Algorithm Development

## 4.1 Framework for algorithm development

The most common, and thus most developed, way to characterize the lands ability to withstand repeated impacts from both military and land management activities is based on the dynamic and complex nature of above- and below-ground biomass. The fact that soil organisms are sensitive to changes in their environment provides the opportunity to identify impacts of land use that may not otherwise be immediately obvious. Ideally, such indicators should be able to alert land managers of deviations from desirable soil conditions. Biological indicators have proven useful in predicting how land management practices affect long-term productivity and soil loss. However, such methods have not yet been applied to an investigation of how land management practices in combination with training impacts influence above- and below-ground biomass. To further this investigation this work developed algorithms focused on four aspects of the relation between above- and below-ground biomass and natural resource disturbance:

1. use of above- and below-ground biomass to quantify disturbance
2. forecasting soil temperature and moisture as a consequence of weather
3. distribution of training and its impacts on biomass
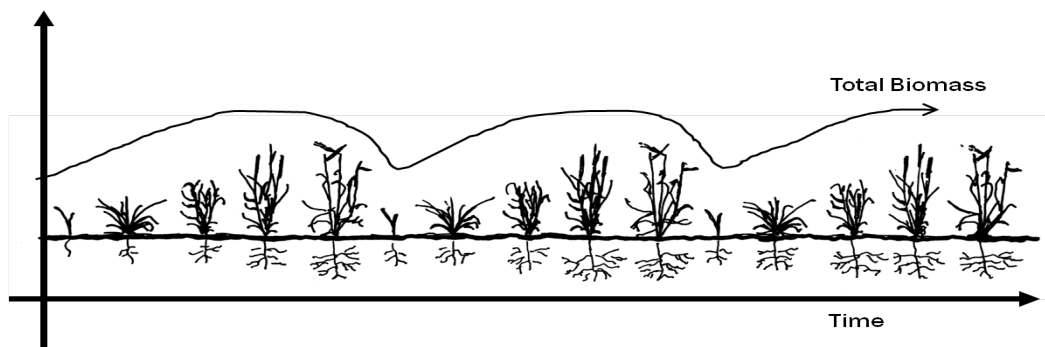4. impacts of burning/haying on land management.



Figure 4. Biomass lifecycle.

## 4.2 Algorithms

Disturbance algorithms characterize the quantity of above- and below-ground biomass of grasslands over time based on the disturbances of vehicle maneuvers, haying, and prescribed burning. These disturbances consist of five modules, which are conceptually based on three CENTURY modules. Figure 5 shows these modules and their interactions, which together simulate the growth and death of biomass. Impacting the growth and death are: (1) climatic patters, (2) soil conditions, (3) land management activities, and (4) tracked-vehicle training patterns.
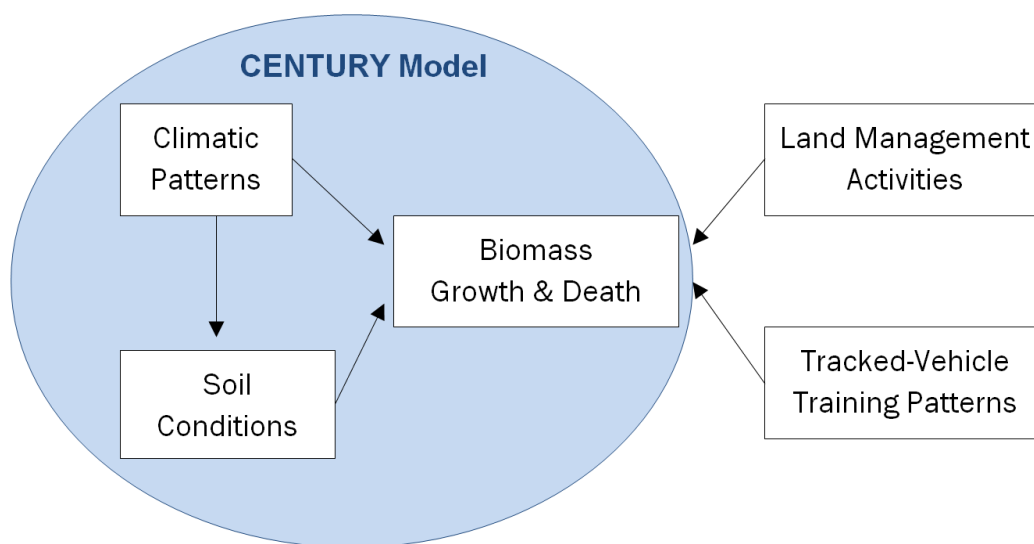
Figure 5. Disturbance regime concept.

The biomass module grows shoots and roots at its maximum plant production rate. Factors that modify growth rate are rainfall, temperature, soil moisture, soil temperature, and soil compaction. Additional biomass gain/loss may come from the land management activities (e.g., haying and prescribed burning) or tracked-vehicle training. Each of these activities removes an amount of above-ground biomass and has varying impacts on below-ground biomass. For example, haying gradually destroys root growth whereas prescribed burns stimulate root growth.

### 4.2.1 Above-ground biomass

The vegetation growth model for the OPAL model is based on components of the CENTURY model (NREL 2006, Parton et al. 1993). CENTURY is a computer model of plant-soil ecosystems that simulates the dynamics of

grasslands, forest, crops, and savannas with a focus on nutrient (carbon, nitrogen, phosphorous, and sulfur) cycle estimation. The plant production submodel of the CENTURY model was used as the basis for the OPAL biomass modeling approach. In the CENTURY model, potential plant production is calculated as a function of soil temperature, soil moisture, and a self shading factor (Equation 1). This document provides an overview of the main functions of the model and their parameters. Koch et al. (2013a) provide a comprehensive description of the model and documentation of the NetLogo code as:

$$P_p = P_{max} * T_p * M_p * S_p$$                                              Equation 1

where:

$P_p$ = above-ground potential plant production rate (g m$^{-2}$ month$^{-1}$)
$P_{max}$ = maximum potential above-ground plant production rate
$T_p$ = effect of soil temperature on growth (unitless)
$M_p$ = effect of soil moisture on growth (unitless)
$S_p$ = effect of plant shading on growth (unitless)

$T_p$, and $M_p$ are calculated by Equations 2 and 3, respectively:

$$T_p = \exp\left[\left(\frac{ppdf(3)}{ppdf(4)}\right) * \left(1 - \left(\frac{ppdf(2)-ctemp}{ppdf(2)-ppdf(1)}\right)^{ppdf(4)}\right)\right] * \left(\frac{ppdf(2)-ctemp}{ppdf(2)-ppdf(1)}\right)^{ppdf(3)}$$   Equation 2

where:

Tp = effect of soil temperature on growth (unitless) (tempM in NetLogo Model)

ppdf(1) = optimum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth (30 for Konza - crop.100)

ppdf(2) = maximum temperature for production for parameterization of a Poisson Density Function curve to simulate temperature effect on growth (45 for Konza - crop.100)

ppdf(3) = left curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth (1 for Konza - crop.100)

ppdf(4) = right curve shape for parameterization of a Poisson Density Function curve to simulate temperature effect on growth (2.5 for Konza - crop.100)

ctemp = average soil surface temperature (°C).

$$M_p = 1.0 + \left( \frac{\left( \frac{avh2o(1)+prcurr(month)+irract}{pet} \right) - pprpts(3)}{pprpts(3) - pprpts(1) - pprpts(2) * wc} \right) \qquad \text{Equation 3}$$

where:

|  |  |  |
|---|---|---|
| $M_p$ | = | effect of soil moisture on growth (unitless) - (limited from 0.0-1.0) |
| avh2o(1) | = | water available to plants for growth in soil profile (cm) |
| prcurr(month) | = | precipitation in current month (cm) |
| irract | = | amount of irrigation water in the current month (cm) (Note that this variable is not needed for Fort Riley) |
| pet | = | potential evapotranspiration rate for month (cm) (see below) |
| pprpts(1) | = | the minimum ratio of available water to PET that would completely limit production assuming water content is equal to 0. Valid Range: 0.0 to 1.0. (For Konza = 0, fix.100) |
| pprpts(2) | = | the effect of water content on the intercept , allows the user to increase the value of the intercept and thereby increase the slope of the line. (For Konza = 1.0, fix.100) |
| pprpts(3) | = | the lowest ratio of available water to PET at which there is no restriction on production. Valid Range: 0.0 to 1.0 (For Konza = 0.8, fix.100) |
| wc | = | afiel(1) - awilt(1) = field capacity of top soil layer - wilting point of top soil layer (unitless fraction 0.0-1.0). |

### 4.2.2 Below-ground biomass

The CENTURY model estimates below-ground biomass according to a root-to-shoot ratio estimated from the cumulative rainfall to that point (NREL 2006) (Equation 4). However, the above-ground biomass model described in the previous subsection estimates live above-ground biomass. While above-ground biomass may die during the senescent periods, most grassland species below-ground biomass remains dormant during this period. To model this behavior, the OPAL NetLogo model assumes below-ground biomass temporarily remains unchanged if estimated below-ground biomass (from the root-to-shoot ratio) is lower than the previous time-step below-ground biomass. Following the estimation of a below-ground biomass due to root-to-shoot ratio, root death is calculated based

on available soil moisture. As modeled, above-ground biomass growth essentialy drives below-ground biomass growth while soil moisture conditions drive below-ground biomass death.

$$RS_{Ratio} = \frac{(100 + cumulative\ precipitation * 7)}{-40 + cumulative\ precipitation * 7.7}$$ Equation 4

### 4.2.3 Soil temperature and moisture

Soil temperature is calculated from the maximum and minimum air temperatures for the week and above-ground biomass cover (NREL 2006). Calculated soil temperature is an average of the maximum and minimum calculated from the air temperatures. The soil temperature is calculated in degrees Celsius (°C) and is assumed to be uniform across the root depth:

$$t_{soilmin} = t_{airmin} + 0.004 * abovegroundbiomass - 1.78$$ Equation 5

$$t_{soilmax} = t_{airmax} + \left(\frac{25.4}{1 + 18 * e^{(-0.2 * t_{airmax})}}\right) * (e^{-0.0035 * abovegroundbiomass} - 0.13)$$ Equation 6

$$t_{soil} = \frac{t_{soilmin} + t_{soilmax}}{2}$$ Equation 7

Soil moisture is then calculated by the following moisture balance model:

$$\theta_t = \theta_{t-1} + \frac{\left[i * \frac{1}{10}\left[\frac{cm}{mm}\right] - ET_{obs} - K_{sat} * K_r * 7\left[\frac{day}{week}\right] * 24\left[\frac{hr}{day}\right]\right]}{L}$$ Equation 8

where:
- $\theta_t$ = soil moisture (m/m)
- $\theta_{t-1}$ = soil moisture from previous week (m/m)
- $ET_{obs}$ = observed or actual evapotranspiration (cm/week)
- $K_{sat}$ = saturated hydraulic conductivity (cm/hr)
- $K_r$ = relative hydraulic conductivity (unitless); calculated using Van Genuchten's closed-form equation for estimating unsaturated hydraulic conductivity (Van Genuchten 1980)
- $L$ = depth of soil layer.

Potential evapotranspiration is estimated using the Blaney-Criddle Method (Brouwer and Heibloem 1986, Schwab et al. 1993). The Blaney-Criddle Method is a simple, empirical evapotranspiration model and is a function of average temperature and mean daily percentage of annual daytime hours:

$$ET_O = p * (0.46 * t_{mean} + 8)$$ Equation 9

where:

$ET_O$ = potential evapotranspiration rate (mm/day)
$P$ = mean daily percentage of annual daytime hours
$t_{mean}$ = mean weekly temperature (°C).

As described by Dyck (1983), potential evapotranspiration does not accurately describe the actual evapotranspiration observed. If soil moisture is lower, associated actual evapotranspiration rates for soil water balance calculations will be lower. A simple method for estimating actual evapotranspiration using relative soil moisture does not require any additional parameters, but models the reduction of actual evaporation with the reduction of available soil moisture:

$$ET_{obs} = ET_{pot} * (\theta_i - \theta_{wp})/(\theta_{sat} - \theta_{wp})$$

Equation 10

where:

$ET_{obs}$ = observed or actual evapotranspiration
$ET_{pot}$ = potential evapotranspiration
$\Theta_i$ = soil moisture (m/m)
$\Theta_{wp}$ = soil moisture at wilting point (m/m)
$\Theta_{sat}$ = soil moisture at saturation (m/m).

### 4.2.4  Training distribution and impacts

Historically, military land management has had a critical (and unmet) need to estimate training distribution and impacts. Generally, the installations' Range Facility Management Support System (RFMSS) databases are used to attempt to quantify training impacts (Davis 2005). While implemented by Army installations, RFMSS is lacking in several aspects:

1. There is a paucity of detailed training intensity information.
2. The spatial scale, which is usually at a training area level, leads to an overestimation of the spatial distribution of training impacts.
3. Data are often not recorded as thoroughly as necessary.

The US Army Training and Testing Area Carrying Capacity (ATTACC) was developed and implemented as part of the ITAM program (USAEC 1999). The overall objective of the ATTACC methods is to estimate training land carrying capacity by estimating training impacts. The ATTACC methodology links training impacts to the RFMSS database to estimate overall

training impact. From ATTACC methodology, it is possible to estimate the number of Maneuver Impact Miles (MIM) trained in that training area by:

$$MIM = \sum_{V=1}^{v}(Number_V * Mileage_V * VSF_V * VOF_V * VCF_V * LCF)$$  Equation 11

where:

MIM = Maneuver Impact Mile (the equivalent damage of one M1A2 travelling 1 mile)

V = vehicle type (dimensionless)

V = number of types of vehicles training in area for the week

$Number_V$ = number vehicles of type, V, training in area

$Mileage_V$ = average mileage driven per vehicle, V

$VSF_V$ = vehicle severity factor

$VCF_V$ = vehicle conversion factor

$VOF_V$ = vehicle off-road factor

LCF = land condition factor (Sullivan and Anderson 2000).

Two levels of training data fidelity can be used as inputs to the model: (1) RFMSS level data including all of the information described in Equation 11 except for the vehicle mileage, or (2) a generic indication of training intensity, quantified as the "average number of MIMs per training area," which ranges from 1 to 3.

Using methodologies described by Svendsen et al. (2013), Equation 12 then estimated the change in vegetation to each patch given the training load estimated. Estimates of training impact on below-ground biomass were made based on literature review and field data. The LCF accounts for different in training impact due to moisture condition. LCF is calculated by taking a ratio of a reference soil moisture rating cone index (RCI) to the actual soil moisture RCI and raising the resulting value to the power of 5/3 (Sullivan and Anderson 2000):

$$\Delta(AGB) = \frac{MIM[mi]*MCF\left[\frac{m^2}{mi}\right]*AGB\left[\frac{g}{m^2}\right]}{A[m^2]}$$  Equation 12

where:

AGB = Above-Ground Biomass [g/m²]

MIM = Maneuver Impact Miles [mi]

MCF = MIM Conversion Factor = area impacted by 1 MIM [m²/mi]

A = total area of patch [m²].

As documented in ATTACC methodologies, the distribution of training across maneuver areas is difficult to estimate. Ayers et al. (2007) and Koch et al. (2012) have discussed methods to obtain high spatial and temporal resolution training distribution and impact data through global positioning system (GPS) based vehicle tracking systems; however this is likely not economically or practically feasible for a large number of training events across many installations. As such, methods to estimate a distribution of training within a training area (e.g., lowest resolution data widely available through RFMSS) are desired.

An approach developed by Guertin (2000) for Fort Hood, TX estimated a probability surface that defines areas more likely to be impacted by training maneuvers. This approach is based on a logistic regression of observed disturbance data on a set of independent variables that appeared to influence training distribution (slope, vegetation type, installation region, and distance from maintained roads). Fang et al. (2002) performed an uncertainty analysis of the disturbance model developed by Guertin and concluded that the error and uncertainty in the vegetation map were the dominant sources of mapping uncertainty. This approach provides a better solution than assuming an even distribution across each training area.

### 4.2.5  Burning and haying/mowing land management impacts

A burning component to the above-ground biomass was added based on CENTURY model assumptions (NREL 2006). The CENTURY model assumes three levels of fire intensity that remove between 60–80% of the above-ground biomass. For the initial OPAL model development and demonstration, a medium fire intensity (70% reduction) was assumed since fire intensity was not an attribute of the documented prescribed burn/wildfire dataset. As such, if the burning data state a particular patch was burned during the week, the above-ground biomass component was reduced by 70% from the non-burned calculated value. Below-ground biomass was determined based on a mixed linear model where given soil conditions, percent increases, or decreases in below-ground biomass are estimated by treatment conditions (Fulton 2013).

A haying component was added that is similar to the previously described burning component. The model assumes that 90% of the above-ground biomass is removed if the haying schedule predicts that the referenced

patch was hayed during that time schedule. The impact on below-ground biomass was estimated from the same mixed linear model (Fulton 2013).

## 4.3  Floristic quality

Botanists and plant ecologists sometimes use a quantitative measure called the Floristic Quality Index (FQI) to express the "quality" of a natural area. This standardized tool replaces subjective assessments, and although approximate, provides a useful number for comparing natural areas. A floristic quality predictor function was added to the model and included species composition data, disturbance history, burn history, haying history, and climate history.

This component used in Fort Riley, KS, Land Condition Trend Analysis (LCTA) data from 1989 through 2001, which included measurements for percent bare ground, litter, annual cover, perennial cover, and military training disturbance (based on visible identification of damage to vegetation from anthropogenic sources) taken using 100 points sampled along a permanent 100 m transect. Drip height was also calculated by measuring the mean maximum height of vegetation at each sampling point. Years 1994 through 2001 contained plant species composition measurements that were obtained by taking point intercept measurements in permanent 10 m plots late each spring. Points were placed every 0.1 m for the first 2.0 m, and every 0.5 m from 2.0 to 10.0 m, and at heights of 0.1, 0.2, 0.4, 0.5, and 0.7 m at each location. Each species was assigned a Coefficient of Conservatism (C) based on values assigned to species occurring in Kansas (Freeman 2012). Because Carex species were only recorded as genera, a C value of 5.33 was assigned to each Carex entry, based on the average C value for all 24 Carex species with documented occurrence in the two counties (Geary and Riley) where Fort Riley resides (NRCS 2013). Plant quality was measured using the Adjusted Floristic Quality Index (Rocchio 2007), which calculates a FQI by multiplying the mean C value for all species by the square root of measured species richness, giving introduced species a C value of 0, but including them in the species richness count.

Fire history was calculated from litter cover using the following criteria validated using satellite imagery: burn was assumed to have occurred when litter decreased by ≥ 35% when military training disturbance is ≤ 50%, or litter decreased by ≥ 50% when military training disturbance is ≥ 50%.

Haying history was calculated from those plots residing in hay lease areas by using drip height measurements. Haying was assumed to have occurred when drip heights were ≤ 0.2 m or dropped by ≥ 50% from the prior year in the absence of fire and when military training disturbance was ≤ 60%.

Climate data for Manhattan, KS were obtained from the National Climatic Data Center (www.ncdc.noaa.gov) and included mean maximum and minimum monthly temperatures, mean monthly temperatures, and total monthly precipitation.

Soil series for each plot were obtained by overlaying plot coordinates over a soils series map. When plots contained more than one soil series, the proportional coverage of each soil series was used to calculate an average value for soil variables for each plot. Soil variables were obtained from the following Kansas county soil surveys (for the available year) (USDA 2013):

| | | | |
|---|---|---|---|
| Clay (1984) | Marion (1985) | Nemaha (2005) | Saline (1992) |
| Dickinson (1980) | Marshall (1980) | Osage (1985) | Wabaunsee (1991) |
| Geary (2005) | McPherson (1983) | Pottawatomi (1987) | Washington (1993) |
| Jewell (1984) | Morris (1974) | Riley (1975) | |

Table 1 lists predictor variables used for model construction. The PROC REG procedure was used in SAS for model construction, using 20 iterations and adjusted $R^2$ and AIC as model selection parameters. The final solution for the PROC REG procedure yielded a model with 16 predictor variables, an adjusted $R^2$ of 0.6583, and AIC value of 799.1776. However, because PROC REG is sensitive to missing values, this model was constructed using only 575 of the 1036 observations. Collinearity was assessed using the VIF and COLLINOINT options for PROC REG and collinear predictor variables were removed based on variance inflation. PROC GLM with the SOLUTION command was used to include missing observations to ensure greater incorporation of observations.

Table 1. Variables used in floristic quality model construction.

| Soil Properties | Climate Properties | Vegetation Properties | Land Use Properties |
|---|---|---|---|
| productivity | previous growing season length | percent bare ground | burned or unburned |
| depth | last frost date | percent annual cover | burned or unburned prior year |
| water holding capacity | previous year's heating degree days | prior year's annual cover | burned or unburned 2 years prior |
| texture | previous year's growing degree days | annual cover 2 years prior | burned or unburned 3 years prior |
| permeability | previous year's total precipitation | annual cover 3 years prior | number of burns prior 2 years |
| | spring precipitation | mean annual cover for prior 2 years | number of burns prior 3 years |
| | winter precipitation | mean annual cover for prior 3 years | number of burns prior 5 years |
| | spring minimum temperature | mean annual cover for prior 5 years | percent disturbance |
| | spring maximum temperature | percent perennial cover | percent disturbance prior year |
| | winter minimum temperature | prior year's perennial cover | percent disturbance 2 years prior |
| | winter maximum temperature | perennial cover 2 years prior | percent disturbance 3 years prior |
| | | perennial cover 3 years prior | percent disturbance 5 years prior |
| | | mean perennial cover for prior 2 years | mean percent disturbance for prior 2 years |
| | | mean perennial cover for prior 3 years | mean percent disturbance for prior 3 years |
| | | mean perennial cover for prior 5 years | mean percent disturbance for prior 5 years |
| | | prior year's FQI | mowed or unmowed |
| | | FQI 2 years prior | mowed or unmowed prior year |
| | | FQI 3 years prior | mowed or unmowed 2 years prior |
| | | mean FQI for prior 2 years | mowed or unmowed 3 years prior |
| | | mean FQI for prior 3 years | mowed or unmowed 5 years prior |
| | | mean FQI for prior 5 years | number of mows prior 2 years |
| | | | number of mows prior 3 years |
| | | | number of mows prior 5 years |

This procedure used 814 of the 1036 total observations, and resulted in a model with six predictor variables and an R² of 0.6238. The full model selected is:

FQI = 5.249597 – 0.002024 * (productivity) – 0.207989 * (winter precipitation) + 0.654188 * (last year's FQI) + 0.023707 * (peren nial cover) + 0.340036 * (number of burns previous 2 years) – 0.019402 * (disturbance)

where:

*Productivity* is estimated average biomass production in g m⁻².

*Winter precipitation* is total precipitation occurring in the months of January, February, and March in inches.

*Last year's FQI* is the calculated FQI value from the previous year's species composition data.

*Perennial cover* is the percent of sampled area occupied by perennial plant species.

*Number of burns previous 2 years* is the total number of times the area was burned in the previous 2 years.

*Disturbance* is the percent of the sampled area visibily disturbed by military training.

Last year's FQI has a significant impact on FQI estimation; without this variable, estimation with precision is very difficult. To estimate FQI without knowing the prior year's value, the best fit model was developed following the procedures outlined above. The best fit predictor model contained 15 variables and had an R² of 0.3907.

# 5   Conclusion

The Optimal Allocation of Land for Training and Non-Training Uses (OPAL) Program was developed to describe and model the influences that military land use (training and non-training) have on above- and below-ground biomass. This phase of work developed algorithms for estimating cumulative land disturbance on military training lands through above- and below-ground biomass responses. Specifically, this work developed algorithms that focused on four aspects of the relation between above- and below-ground biomass and natural resource disturbance:

1.  use of above- and below-ground biomass to quantify disturbance
2.  forecasting soil temperature and moisture as a consequence of weather
3.  distribution of training and its impacts on biomass
4.  impacts of burning/haying on land management.

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# Acronyms and Abbreviations

| Term | Definition |
|---|---|
| °C | Degrees Celsius |
| AEC | Army Environmental Command |
| AEPI | Army Environmental Policy Institute |
| AGB | Above-Ground Biomass |
| ANSI | American National Standards Institute |
| AR | Army Regulation |
| ASABE | American Society of Agricultural and Biological Engineers |
| ATTACC | Army Training and Testing Area Carrying Capacity |
| BLM | Bureau of Land Management |
| C | Coefficient of Conservatism |
| CAA | Concepts Analysis Agency |
| CEERD | US Army Corps of Engineers, Engineer Research and Development Center |
| CERL | Construction Engineering Research Laboratory |
| CFR | Code of Federal Regulations |
| cm | Centimeter |
| DoD | US Department of Defense |
| EDYS | Ecological Dynamics Simulation |
| EL | Environmental Laboratory |
| ELVS | Evaluation of Land Value Study |
| ERDC | Engineer Research and Development Center |
| ERDC-CERL | Engineer Research and Development Center, Construction Engineering Research Laboratory |
| ERDC-EL | Engineer Research and Development Center-Environmental Laboratory |
| ESA | US Endangered Species Act |
| FORPLAN | Forest Planning Language and Simulator |
| FQI | Floristic Quality Index |
| FY | Fiscal Year |
| g | Grams |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GSSHA | Gridded Surface Subsurface Hydrologic Analysis |
| HQDA | Headquarters, Department of the Army |
| hr | Hour |
| IAHS | The International Association of Hydrological Sciences |
| INRMP | Integrated Natural Resources Management Plans |
| ISTVS | International Society for Terrain-Vehicle Systems |
| ITAM | Integrated Training Area Management |
| LCF | Land Condition Factor |

| Term | Definition |
|------|------------|
| LCTA | Land Condition Trend Analysis |
| LR | Letter Report |
| m | Meter |
| MCF | MIM [Maneuver Impact Mile] Conversion Factor |
| MIM | Maneuver Impact Mile |
| NATO | North Atlantic Treaty Organization |
| NCR | National Research Council |
| NEPA | National Environmental Policy Act of 1969 |
| NRCS | Natural Resources Conservation Service |
| NREL | National Renewable Energy Laboratory |
| NRMM | NATO Reference Mobility Model |
| NSN | National Supply Number |
| OMB | Office of Management and Budget |
| OPAL | Optimal Allocation of Land for Training and Non-Training Uses |
| PET | Potential EvapoTranspiration |
| POM | Program Objective Memorandum |
| QA/QC | Quality Assurance/Quality Control |
| RCI | Rating Cone Index |
| RFMSS | Range Facility Management Support System |
| RUSLE | Revised Universal Soil Loss Equation |
| SAR | Same as Report |
| SCS | Soil Conservation Service |
| SF | Standard Form |
| SPOT | Systeme Probatoire pour l'Observation de la Terre |
| SR | Special Report |
| SRP | Sustainable Range Program |
| TATM | Technical and Technology Assessment and Transition Management |
| TEPC | Threatened, Endangered and Proposed Candidate |
| TES | Threatened and Endangered Species |
| TN | Technical Note |
| TR | Technical Report |
| UK | United Kingdom |
| US | United States |
| USA | United States of America |
| USACERL | US Army Construction Engineering Research Laboratory |
| USDA | US Department of Agriculture |
| USAEC | US Army Environmental Command |
| USFS | US Forest Service |
| VCF | Vehicle Conversion Factor |
| VDMTS | Vehicle Dynamics Monitoring and Tracking System |
| VOF | Vehicle off-Road Factor |
| VSF | Vehicle Severity Factor |

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**14. ABSTRACT**

Proper management of military training lands is critical to ensure availability of training lands, and thereby ensure mission readiness. However, installation land management often supports a broader mission than simply maintaining the land in a condition suitable for training, including activities as agriculture and grazing outleases, and protection of habitat to conserve Federally listed threatened and endangered species. Proactive land management practices that support such potentially conflicting land uses must take a systematic approach that considers, coordinates, and integrates complex land impacts. Development of the Optimal Allocation of Land for Training and Non-Training Uses (OPAL) Program was undertaken to meet this need. This phase of work developed algorithms for estimating cumulative land disturbance on military training lands through above- and below-ground biomass responses. Algorithms developed here specifically focused on four aspects of the relation between above- and below-ground biomass and natural resource disturbance: (1) use of above- and below-ground biomass to quantify disturbance, (2) forecasting soil temperature and moisture as a consequence of weather, (3) distribution of training and its impacts on biomass, and (4) impacts of burning/haying on land management.

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